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ABSTRACT

The main purposes of this study were to determine: (1) how high school students represent the physical phenomena of phase changes; (2) how they modify their representation of these physical phenomena to accommodate new observation; (3) what factors lead to student difficulty in modifying representations; and (4) how the field-dependence/independence construct relates to the character of the models and receptivity to feedback. A videotape was prepared of five experiments that involved the phenomena of phase change under various conditions. An introductory question about solids, liquids, and gases was asked to determine recall independent of context. Then for each experiment the subject was shown the apparatus and was asked what will happen when a certain procedure is carried out. The subject was then asked to justify his or her answer. The subject then observed the experiment and was asked to describe everything that he or she observed. At the conclusion of the experiment, the subject was asked if the prediction was accurate. The population was composed of 20 above-average high school students in a suburban high school. It was found that students' theories were often fragmented and "unscientific." When they differed from those of the expert, they fell into one or more of five categories, i.e., they were based on macro-level properties, unacceptable scientific theories, inappropriately applied theories, internally inconsistent explanations, or "rule" based justifications. (18 references) (Author/KR)

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REPRESENTATION AND FEEDBACK IN THE FORMATION OF A PHYSICAL SCIENCE CONCEPT

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Abstract

REPRESENTATION AND FEEDBACK IN THE FORMATION
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The main purposes of this study were to determine 1) how high school students represent the physical phenomena of phase changes, 2)how they modify their representation of these physical phenomena to accommodate new observations, 3) what factors lead to student difficulty in modifying representations and 4)how the field-dependence-independence construct relates to the character of the models and receptivity to feedback

A video tape was prepared of five experiments which involved the phenomena of phase change under various conditions. An introductory question about solids, liquids and gases was asked to determine recall independent of context. Then for each experiment the subject was shown the apparatus and was asked what will happen when a certain procedure is carried out. He was also asked to justify his prediction. The subject then observed the experiment and was asked to describe everything that he observed. At the conclusion of the experiment he was asked if the prediction was accurate. If not, he was asked how the observed phenomena can be explained. The experimenter asked questions to clarify or expand on what was already indicated by the subject. The population was composed of above average high school students in a suburban high school.

It was found that students' theories were often fragmented and "unscientific". When they differed from those of an expert, they fell into one or more of five categories. They were based on 1) macro level properties, 2) unacceptable scientific theories, 3) inappropriately applied theories, 4) internally inconsistent explanations or 5) " rule " based justifications.

The students generally did not use many molecular or "abstract/interaction" level representations that were considered relevant. Subjects used more molecular representations than "abstract/interaction" representations but this was often in conflict with an expert's representation.

Although there wasn't a significant difference for the overall protocol, there was a significant different between the groups for a section of the protocol.

The ability to predict the outcome of an experiment ranged from 0 to 4.5 correct predictions. It was also found that there was a low correlation between the number of correct responses on the molecular level and predictions but an moderate correlation between the number of correct responses on the abstract/interaction level and predictions.

Introduction

Although individuals observe science related phenomena in everyday experiences and may study science for many years, they often have strongly held misconceptions and/or naive representations of the phenomena (Chi, 1982; Chi, 1987; McCloskey, 1987; Clough, 1986; Clement, 1982; Renstrom, 1987; Trowbridge, 1988). Failure of instruction to change these misconceptions may be due to the manner in which prior knowledge is stored or the means by which new knowledge is assimilated and accommodated.

In order to be an effective problem solver in science, an individual must be able to restructure problems. The salient information must be extracted from the problem and related to relevant models. Poor representation of the problem appears to be a major cause of difficulty in restructuring science problems. If poor representation is the case, it may be poor representation due to well formed misconceptions (McCloskey, 1983), or a lack of understanding of the fundamental principles governing behavior, i.e., fragmented knowledge (diSessa, 1987; BouJaoude, 1989; Champagne, 1986).

Until recently the study of science in schools involved mainly the memorization of a collection of facts. In the area of chemistry, for example, emphasis was placed on the memorization of physical and chemical properties of many "important" compounds. The laboratory experiments involved preparation of these compounds and testing of their properties.

With the advent of the post Sputnik era, science curricula, especially chemistry, were modified to include less description and more models and applications. Emphasis was placed on quantitative relationships, properties on the macro and molecular level and structural reasons for these properties. This approach requires much more problem solving and abstract reasoning. Although this is the emphasis, many beginning students seem to be deficient in basic concepts of the atomic model and how it is related to macroscopic properties and laws (Ben-Zvi, 1988; Andersson, 1980; Griffiths and Preston, 1989)

In the study of chemistry, the processes can be quite complex. First, the natural phenomena is observed. Then, it is explained in terms of models of atoms and molecules. In order to predict changes and properties, an understanding of how these entities interact due to fundamental principles must be developed. Finally, symbolism essentially unique to science must be used to represent it. The student is thus required to progress through three levels of representation -the macro level the molecular level and the abstract/interaction level (ex. pressure, force etc). Although representation is often divided into macro (concrete) and micro (abstract), three levels will be considered in this study because it is postulated that molecular level concepts can be more easily described by concrete analogies than can the interaction level. This should result in greater assimilation and application of the molecular level than the abstract/interaction level.

Often the terminology used is common to both the scientific and general communities, for example, pressure or force. Students learn different representations by rote but can not connect them. Because of the similarity of the symbolism, new knowledge is often stored and/or retrieved improperly. Therefore, they can not restructure the problem or correctly apply algorithms to non-routine problems. If the student fails to correctly predict the correct answer to the problem, the failure may be due to any one of many errors in representation or procedures.

Purpose

The purpose of this study was to determine how high school students represent the physical phenomena of phase changes, how they modify their representation of these physical phenomena to accommodate new observations and which factors lead to student difficulty in modifying representations. The following questions are addressed in this paper:

1. What are the "models" or "theories" students hold about specific physical science phenomena?

2. How do participants utilize feedback?

3. Does a field-dependence-independence construct relate to the character of the models and receptivity to feedback?

Significance

Research has shown that in spite of considerable science instruction students often have many of the misconceptions they held before such study. If it can be determined which characteristics contribute to the successful modification of student

representations or impede such modifications, educators can design instruction which will help establish the desired characteristics. Finally, if it is found that observation of a sequence of experiments which build on each other assists the teacher and or the student to detect difficulties in representation, this may prove to be an effective means of representation modification and construction.

Design and Procedures

Design

Since boiling is a common phenomena and one that is studied beginning with elementary science and continuing through chemistry, this phenomena was chosen. Some critical concepts included in the study of phase change from liquid to gas are temperature, heat, vapor pressure and intermolecular attractions. In order to determine the representation of these concepts and the ability of the participant to relate them to a particular problem, a series of experiments were included in the protocol.

The first experiment involved a familiar situation- water heated under atmospheric conditions. This allowed the researcher to determine the representation of boiling with respect to heat and temperature. In order to determine how the participant utilizes the concept of vapor pressure, in the second experiment water is observed as the pressure is reduced. This experiment also allows for an expansion of the concepts of heat and temperature. Then, in order to determine if the participant's schema includes a concept

of intermolecular forces, the third experiment involves water and alcohol at reduced pressure. The final two experiments are designed to determine how the observations in the first three experiments are used to predict observations in a new environment. The changes that occur when a liquid, originally at a higher than atmospheric pressure, is poured into a tube can only be accurately explained by using all of the above concepts. If water is added to the liquid the concept of heat transfer from one substance to another must be included in the mental model.

Materials

The materials used include the Group Embedded Figures Test (Witkin, Oltman, Raskin and Karp, 1971) and a video tape of five experiments. This was done to ensure that all students had an opportunity to obtain the same information. The entire video was eighteen minutes in length.

Participants

The population was composed of high school students in a suburban high school, who had successfully completed a chemistry course or who were presently enrolled in such a course and had already studied the subject matter involved in this study. The chemistry course is a course designed for above average college preparatory students. The students were also in above average mathematics classes. The Group Embedded Figures Test was given to all volunteers. From this population twenty participants were chosen to be interviewed about science concepts and experiments. The participants included ten field independent and ten field

dependent individuals.

Protocol

An introductory question about solids, liquids and gases was asked to determine recall independent of context. Then for each videotaped experiment, the participants were shown the apparatus and were asked what will happen when a certain procedure is carried out. They were also asked to justify their prediction. Each participant then observed the experiment and was asked to describe everything that was observed. At the conclusion of the experiment the participant was asked if the prediction was accurate. If not, an explanation of the observed phenomena was requested. The experimenter asked questions to clarify or expand on what was already indicated by the participant. Finally, questions were asked to ensure that the participants had an opportunity to address all relevant areas. The experiments begin with simple and familiar conditions and proceed to less familiar and more complex conditions.

An expert was interviewd in the same manner as the students. The protocol of the expert was reviewed to determine what would be considered a complete answer for each section. Each of the relevent representations used by the expert were assigned a value of 1 or 2 points. The total number of points assigned to each section was ten. The representations were also classified as macro, molecular or abstract/interaction level by two chemistry teachers. Ninety seven percent of the representations were classified the same way. Of those that were different, the second

teacher actually gave two categories. The preferred choice differed from that of the first scorer but the second possibility was the same as the first scorer had classified them.

Two chemistry professors and a high school chemistry teacher evaluated the student protocols. Ninety five percent of the scores were the same for at least two of the three judges. The score for a section is that given by two or more judges or if no two judges gave the same score, the average score of the three.

Results

The participants differed from each other and the expert in many areas. The most pronounced areas were:

1. Type and levels of representation
2. Accommodation and modification of models (theories)
3. Perception of physical phenomena
4. Interpretation and ability to adjust to changes in context.

Representations and conceptual understanding were analyzed in phases. The first was to determine the overall conceptual understanding of students compared to the expert in each section. This was done by comparing the student's responses to the expert's, using the 0 -10 scale developed from the expert's protocol. The scores of the protocols ranged from 12 to 42. Nine of the participants scored between 20 and 29 out of 60. Only two participants, one field dependent and the other field independent, scored above 40. These two participants were also among the participants with the highest number of correct predictions 3.0 and 4.5 (Table 1).

Table 1

Protocol Ratings - Background and Experimental Sections

PARTICIPANT NUMBER	SECTION SCORES 1	2	3	4	5	6	TOTAL SCORE	CORRECT PREDICTIONS
11	7	4	4	4	1	4	24	2.5
17	3	5	2	4	1	1	16	2
20	5	4	2	2	3	2	18	2
26	6	4	2	2	1	1	16	1.5
27	6	4	2	2	4	2	20	3
28	10	7	6	7	7	4	41	4.5
32	5	6	3	5	4	4	27	3.5
39	3	5	2	4	5	4	23	3
40	4	4	2	4	3	2	19	1
41	7	5	8	8	8	6	42	3
45	6	6	2	4	4	1	23	1.5
53	7	5	2	2	1	4	21	0
53a	2	4	3	5	2	3	19	3
57	4	4	2	4	5	2	21	2.5
65	8	5	6	7	5	3	34	2.5
68	1	3	2	2	3	1	12	1.5
70	6	4	1	4	3	5	23	2
74	7	5	3	3	3	3	24	2
76	4	5	8	8	7	3	35	3
77	6	6	6	7	4	1	30	2.5

Next, the extent to which the participants utilized the abstractions characteristic of the field of chemistry and the appropriateness of the representations utilized to explain phenomena were examined.

It was found that students' theories were often fragmented and "unscientific". When they differed from those of an expert, they fell into one or more of five categories. They were based on 1) macro level properties, 2) unacceptable scientific theories, 3) inappropriately applied theories, 4) internally inconsistent explanations or 5) " rule " based justifications.

Macro level representation and unacceptable theories often overlapped. The use of fragmented formal learning was as prevalent if not more prevalent than everyday science. In fact, most of these unacceptable theories can be traced back to incomplete concepts from formal and/or informal learning situations, including many molecular and abstract/interaction representations pieced together in unacceptable ways.

Theories were temporarily formed to bridge known to unknown. These bridges were often built upon an isolated fact which only had surface characteristics in common with the situation being studied. The underlying principles were in contradiction to the extrapolations made by these students. Thus, these theories collapsed when put to further tests.

Inappropriate theories were generally used when students had to give an explanation in a less familiar situation. The overwhelming number of inappropriate relationships involved using the

gas laws when discussing liquids. This appears to be the case because they looked for cues on the macro level and usually ignored or lacked the ability to give molecular and abstract/interaction explanations.

The manner in which scientific terminology was used during the interview gave additional evidence that supported the concept of fragmentation on both the molecular and abstract/interaction level.

Rule based responses were also common and further demonstrate the shallow and fragmented nature of the subjects' knowledge. Terms were often defined in a way that the subject knew he couldn't support independently and thus would attribute it to an authority.

Most molecular or abstract/interaction level representations used by the expert were not used or were used in an unacceptable manner by the participants. They used more molecular representations than abstract/interaction representations but this was often in conflict with an expert's representation.

Many students were partially successful in predicting outcomes because they based their prediction upon physical similarities but they were unable to explain or extend their predictions because of a lack of representation on the molecular and /or abstract/interaction level. It appears that it is simply a fact stored in isolation rather than a network including molecular and abstract/interaction representations. Thus, when knowledge is retrieved all relevant knowledge is not retrieved spontaneously although it might be easily retrieved if provided the appropriate prompts.

In order to determine the magnitude of the lack of representation each protocol was evaluated with respect to each of the levels - macro level, molecular level or abstract/interaction representation. Using the scoring key, each student's responses were rated as correct, incorrect or absent for each item.

Table 2

Frequency of Responses

Section / Level of Response	Number of Responses		
	Correct	Incorrect	Absent
1			
Macro level	48	1	11
Molecular level	45	2	13
Abstract/interaction	14	1	65
2			
Macro level	60	0	0
Molecular level	10	10	0
Abstract/interaction	25	0	95
3			
Macro level	37	15	8
Molecular level	13	10	37
Abstract/interaction	18	4	58

Table 2 continued

Frequency of Responses

Section / Level of Response	Number of Responses		
	Correct	Incorrect	Absent
4			
Macro level	35	5	0
Molecular level	33	24	39
Abstract/interaction	15	3	42
5			
Macro level	49	29	2
Molecular level	10	6	4
Abstract/interaction	15	7	78
6			
Macro level	48	19	33
Molecular level	0	0	20
Abstract/interaction	4	1	55

The ability to predict the outcome of an experiment ranged from 0 to 4.5 correct predictions. It was found that there was a correlation ($r = 0.298$) between the number of correct responses on the molecular level and predictions but a substancially higher correlation ($r = 0.622$) between predictions and the number of correct responses on the abstract/interaction level. The correlation between macro level responses and predictions is

between the other two (r = 0.516). It appears that although a subject may state correct declarative knowledge on the molecular level, it may not actually be functional unless it is combined with the appropriate abstract/interaction level knowledge. Since critical to this phenomena is the idea of molecular interaction and change a static molecular representation is necessary but not sufficient. The ability to predict future outcomes is also influenced by the accuracy of the participants observations. Based upon the protocols, observations are often profoundly affected by the concepts held on the abstract/interaction level. It was also found that there was a low correlation between the number of correct responses on the molecular level and predictions but an moderate correlation between the number of correct responses on the abstract/interaction level and predictions. It appears that although a subject may state correct declarative knowledge on the molecular level, it may not actually be functional unless it is combined with the appropriate abstract/interaction level knowledge.

When the protocols were reviewed to determine the extent to which students changed their representation, it was found that students recognized that their observations did not match their predictions but minimally adjusted their explanations to fit their observations. Occasional they changed their observations without any change in explanations. Future predictions were based on physical characteristics of previous experiments but not upon theory. Thus the subjects, if they restructured at all, generally did weak restructuring.

The fact that restructuring of the concepts involved molecular composition rather than restructuring involving a abstract/interaction is consistent with the other data which indicates a greater comfort and willingness to operate on this level. In the ten cases of field independent participants all but one showed restructuring. It should be noted that this subject received the lowest overall score for the protocol. The two areas of common restructuring were composition of bubbles and concept of energy and temperature. Although modifications were made, they often did not produce a better model.

In order to use feedback effectively the observations must be interpreted correctly regardless of the subjects ability to explain why a particular phenomena is occurring. Thus, to determine how complexity and unfamiliarity affects the use of feedback, the percent of correct responses in each of the five experiments was compared. Familiarity was considered more important than complexity because the subjects seemed to fail on theoretical explanations even at a very elementary level and depended on superficial resemblance. Also memory studies have shown that familiarity is an important factor in recall and recognition. A comparison of the percent correct macro level descriptions to level demonstrates the validity of this premise.

In order to use feedback effectively the observations must be interpreted correctly regardless of the participants ability to explain why a particular phenomena is occurring. For example, the subject should be able to recognize frost on the outside of a test

tube as an indication that the test tube's temperature below the freezing point of the water on the tube. Thus, to determine how complexity and unfamiliarity affects the use of feedback, the percent of correct responses in each of the five experiments was compared. Since this protocol involved a series of experiments, the second experiment using the same physical environment was considered more familiar than the first. The most familiar and least complex is boiling water under ordinary atmospheric conditions. Thus, this was given a unfamiliarity/ complexity value of 0. Familiarity was considered more important than complexity because the participants seemed to fail on theoretical explanations even at a very elementary level and depended on superficial resemblance. Since the alcohol and water in a vacuum jar followed the water in a vacuum jar, it was placed next on the unfamiliarity /complexity scale with a value of 1. The water in a vacuum jar was given a value of 2. Since the low boiling point liquid environment was probably more complex because the subject wasn't being told that the pressure was changing it could be considered familiar because of the experience with the water in the vacuum jar. Thus it was also given a value of 2. Finally the most complex and unfamiliar was the mixing of the liquid and water. This was given a value of 3. A comparison of the percent correct macro level descriptions to level (see Table 3) demonstrates the validity of this premise.

If the participants had a strong molecular and abstract/interaction representation, the unfamiliarity/complexity

rating would probably be different and not show the relationship that was found in this study.

Table 3

Macro - Level Responses and Unfamiliarity /Complexity Level for Each Experiment

Experiment	Level	% Correct Responses
Boiling Water - atm.	0	100.0
Boiling Water - Vacuum	2	61.7
Boiling Water and Alcohol	1	87.5
Boiling a liquid at r.t.	2	61.3
Mixing water and liquid	3	48.0

It was determined that although there wasn't a significant difference between the field dependent/independent groups for the overall protocol, there was a significant different for the a section. There also appears to be an interaction effect between field dependence and the results for some sections.

Conclusions

Although the subjects took many science courses, it appears that most of the subjects lack a molecular and or "abstract/interaction" representation of the physical phenomena or do not consider the related concepts to be relevant to the problem. This may be due to the fact that today instruction is often linear in nature rather than branched. Future studies should

be designed to determine if instructional modifications will change the conceptual representation of the subjects. This would enable us to determine if network formation increases as instructional branching increases.

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